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Does the brain's reward response occur even without actual reward?

A response to Fielding, Fu & Franz (2017)

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Response to Fielding, Fu & Franz (2017)

Abstract

A recent paper by Fielding, Fu & Franz (2017) argued that the brain's reward response could occur without the presentation of actual reward. We suggest that since a) the event-related potentials reported in this paper are atypical of the previous literature, and, b) a simpler account of the data in terms of sensitivity to outcome frequency cannot be ruled out, the extent to which the brain's reward response can occur without the presentation of actual reward should remain an open question.

Keywords

Feedback-related negativity (FRN)

P300

Event-related potentials

Positive and negative feedback

Recently, Fielding, Fu & Franz (2017) provocatively argued that the brain's reward response could occur without the presentation of actual reward. Evidence for this claim was garnered by inviting participants to guess the outcome of a binary decision made by a computer (either the presentation of an X, or, an X within a circle). Following the participant's guess and after a brief delay (1000 ms), the actual computer response was displayed for 500 ms. After another brief delay (1000 ms), feedback for the trial was then displayed (in the form of ++++ for a match and - - - - for a mismatch) for a further 500 ms. The computer's initial response (one of the two X symbols) represented a form of early, implicit feedback (hereafter, *F1*) in which the participant could potentially resolve whether they had succeeded or failed in guessing the outcome. As a result, the + or - symbols comprising positive or negative confirmation served as a form of later, explicit feedback (hereafter, *F2)*. Two important design features of Fielding et al. (2017) were that a) performance was completely controlled by the computer leading to high (80%), equal (50%) or low (20%) probabilities of wins and losses that were the same for all participants, and, b) electrical activity from the scalp was concurrently recorded to examine the neural response to both implicit and explicit feedback. Their key finding was that during early, implicit feedback (*F1*) the P300 response was larger for negative feedback trials relative to the last 30 trials of positive feedback, in a condition where losses represented 20% and wins represented 80% of outcomes (see their Table 1 and Figure 2). We challenge the idea that this data supports the contention that "the brain's reward response occur even without actual reward" due to questions over ERP morphology and the interpretation of the functionality of P300.

ERP morphology

Fielding et al. (2017) identify both feedback related-negativity (FRN) and the P300 as candidates for neural reward responses that might differentially respond to positive and negative outcome. Using the previous literature to predict the timing and placing of these neural responses, FRN should be maximal at fronto-central sites and occur roughly between 200 – 300 ms after the on-set of feedback (e.g., Frank, Woroch & Curran, 2006; Holroyd, Hajcak & Larsen, 2006). In contrast, the P300 is observed across midline electrodes, increases in amplitude the more posterior the electrode, and peaks anywhere between 250 – 500 ms after stimulus on-set (see Polich, 2007, for a review). For illustrative purposes, we present group average ERP from our own lab (Dyson, Steward & Meneghetti, in preparation) in response to more frequent positive feedback relative to less frequent negative feedback across midline Fz, Cz and Pz electrodes (after Fielding et al., 2017), first using original average reference (Figure 1A). These data confirm a negative-going peak maximal at fronto-central sites around 300 ms after feedback presentation consistent with FRN, and, a positive-going peak maximal at centro-parietal sites around 400 ms after feedback presentation consistent with the P300. To maintain consistency with similar studies by Holroyd, Nieuwenhuis, Yeung & Cohen (2003), and, Hajcak, Holroyd, Moser & Simons (2005), scalp EEG in Fielding et al. (2017) was referenced to average mastoid. Our own average mastoid re-referenced data shown in Figure 1B provides a replication of the morphology in both Holroyd et al. (2003), and, Hajack et al. (2005). Critically, this morphology does not appear to be replicated in Fielding et al. (2017) and may call into question their measurement of event-related potentials time-locked to the on-set of *F1*.

In Figure 1B, Fz and Cz are characterized by an initial large-scale (approximately 10 μV) positive-going voltage that terminates around 200 ms after stimulus on-set, a short negative-going voltage containing the FRN around 300 ms, and then another large-scale positive-going voltage containing the P300 around 400 ms (approximate peak amplitude 16 μV). The examination of Hajcak et al. (2005; their Figure 1) and Holroyd et al. (2003; their Figure 1) show similar patterns of data in terms of these relative voltage changes, the eventual peak amplitude achieved by the P300 – roughly 15 μV in Hajcak et al. (2005), and 18 μV in Holroyd et al. (2003), and, the timing of a discernable P300 peak – approximately 400 ms in Hajcak et al. (2005), and, 350 ms in Holroyd et al. (2003).

Replotting the Fielding et al. (2017) data against own our, their data do not appear to replicate this morphology in at least three regards (see Figure 1B). First, there are no clearly identifiable phasic responses generated by *F1* at any of the three electrode sites plotted (Fz, Cz, Pz). Rather, the whole epoch appears to be characterized by relative amounts of positive-going EEG slow-wave activity. Second, the initial positive-going EEG in Fielding et al. (2017) peaks at a voltage of around 4 μV, a magnitude strikingly less than Hajcak et al. (2005), Holroyd et al. (2003), and our data shown in Figure 1B. Third, their use of a 100 ms mean amplitude window between 300 – 400 ms to measure P300 (while consistent with previous research) actually appears to capture a slight, *negative-going* rather than positive-going component, as shown most prominently at Fz and Cz (also at F3 and F4; Fielding et al., 2017, Figure 2). Similarly, their Figure 3 comparing the first and last 30 trials of negative feedback against positive feedback, is also characterized by the lack of sharp visual evoked responses and the presence of what again appears to be EEG slow-wave

activity. In short, there does not appear to be a discernable P300 component in the Fielding et al. (2017) data.

Furthermore, we are also concerned by the seeming lack of early visual evoked responses in Fielding et al. (2017). A minimal expectation regarding the presentation of a discrete, detectable visual stimulus such as *F1* would be the generation of exogenous evoked responses such as P1 and N1 maximal over parietal-occipital electrodes (see Kanwsiher & Wojciulik, 2000, Figure 1). This is not an unreasonable assumption given that visual evoked responses generated around 200 ms after stimulus on-set have the reliability required to serve as the basis for developing brain-computer interfaces (e.g., Guo, Hong, Gao & Gao, 2008; Liu, Goldberg, Gao & Hong, 2010). Again, for illustration purposes, we present in Figure 2 group average ERP in response to the same feedback in Figure 1, but this time at two parietal-occipital electrodes (PO7 and PO8) using average reference. The data show a clear P1-N1 complex defined by sharp on-sets and off-sets. Comparing this data with Figure 1A, at fronto-central sites both the parietal-occipital N1 and P1 appear to reverse in polarity, giving rise to small 'negative' P1 around 100 ms and a small 'positive' N1 around 200 ms. This reversed N1 component survives the average mastoid transformation (see Figure 1B), signaling the end of the steep, positive-going deflection seen approximately 200 ms following stimulus on-set. Again, contrasting this with the data of Fielding et al. (2017), there are no sharp on-sets or off-sets but rather a slow-wave positive-going response that distinguishes between negative feedback and the last 30 trials of positive feedback across 100 – 300 ms. In addition to the absence of a P300, there do not appear to be any traces of exogenous visual responses in the Fielding et al. (2017) data.

Implicit vs. explicit feedback

One potential criticism of the current comparison is that the data from our Figures 1 and 2, Holroyd et al. (2003), and, Hajcak et al. (2005), represent the neural response to explicit feedback: it might be that the brain's response to later, explicit feedback (Fielding et al.'s *F2*) is simply different to early, implicit feedback (*F1*). These criticisms are allayed somewhat by the results of a relatively similar study, where participants played Rock, Paper, Scissors during electrophysiological recording (Forder & Dyson, 2016). The paradigm echoed a key feature of Fielding et al. (2017) in that after the participant had made their selection, both the opponent and participant responses were displayed, which was then followed by the confirmation of separate win, lose or draw outcome. In this paper, we expressed concern that the response display (i.e., early, implicit feedback) might have made the outcome display (i.e., later, explicit feedback) redundant: "…there is full disclosure of response information (e.g., opponent played Paper, player played Rock) prior to a separate feedback display (e.g., lose)…Hence, an attentive player may be able to infer a 'loss' trial upon the presentation of both responses, thereby rendering the explicit presentation of 'lose' in a separate feedback display redundant…" (Forder & Dyson, 2016, p. 3; see also Heldmann, Russeler & Münte, 2008, for a similar discussion).

As before, Figure 3 show group average event-related potentials from Forder & Dyson (2016) generated by early, implicit feedback across three electrodes (Fz, Cz, Pz) as a function of average reference (Figure 3A). In Figure 3B, we show the same data using average mastoid re-referencing (Figure 3B), and plot the Fielding et al. (2017) data for comparison. The trajectory of the ERP following stimulus on-set is a familiar one and similar to Figure 1B, wherein a large-scale positive-going deflection

is interrupted around 200 ms for a smaller, positive-going deflection, followed by another large-scale positive-going deflection that distinguishes between wins and losses at around 400 ms. It is worth noting that in Forder & Dyson (2016), all computerized opponents were playing in accordance with the mixed-equilibrium strategy (e.g., Abe & Lee, 2011) thereby ensuring a roughly equal number of outcome types. This is in contrast to the data presented in Figure 1B where losses were on the whole rarer than wins, and serve as one potential explanation for the reversal in P300 amplitude between positive and negative outcomes (we will return to this observation in the next section). It should be apparent that when compared against the Fielding et al. (2017) data, their event-related potentials generated by earlier, implicit feedback do not accord with previous data and remain characterized by slow-wave, positive-going activity for loss trials.

A final concern is the absence of any FRN or P300 effects reported during the presentation of *F2* (explicit feedback) in Fielding et al. (2017). Firstly, the appeal to signal-to-noise ratio in this context "…obtaining significant effects in the smaller ERP components might require larger numbers of trials" (Fielding et al., 2017, p.x) does not necessarily follow since presumably roughly the same number of trials were entered into the average for *F1* and *F2*- remember that it *was* possible to measure and analyze P300 during *F1* presentation. Secondly, it does not seem to be the case that FRN replicated a standard effect where losses generate larger negativity than wins (e.g., Gentsch, Ullsperger & Ullsperger, 2009). Figure 3 replots the data from Forder & Dyson (2016) to show a simple comparison between positive (win) and negative (lose) outcomes when this later, explicit feedback was preceded by earlier, implicit feedback. Figure 3A confirms the expected direction in that larger FRN amplitude

was generated for losses relative to wins using average reference, and Figure 3B using average mastoid reference preserves this effect. At the very least, it would be useful to view the morphology of *F2* in Fielding et al. (2017) to ascertain whether their EEG recording captured common evoked responses expected from all visual stimuli (P1, N1) and specific visual evoked responses expected from feedback-related stimuli (FRN, P300). On the basis of the data we currently have available, the resultant waveforms of Fielding et al. (2017) appear to be atypical.

FRN versus P300

Aside from the pragmatic concerns regarding the event-related potentials recorded in Fielding et al. (2017), there are also conceptual concerns of whether stimulus novelty serves as a more parsimonious explanation of the data, independently from any appeal to reward responses. First, it is worth reiterating that Fielding et al. (2017) operationalize "the brain's reward response" as the P300 and not the FRN. However, FRN is a well-documented neural component intimately involved with the coding of better-than-expected or worse-than-expected outcomes (see Hauser et al., 2014, for a review). The larger FRN typically generated by negative outcomes represents a 'dopamine dip' originating in the basal ganglia and projects to higher-order cortical areas, presumably to initiate behavioural change as a result of failure (Holroyd, Hajcak & Larsen, 2006). Given the seemingly fundamental nature of this process, when FRN effects are absent it should be necessary to account for why FRN was not observed, or, was observed but did not modulate in the traditional way. Second, and by the author's own admission, there is no current way to reject the alternative explanation that their P300 effect is simply a reflection of sensitivity to rare versus frequent events: "…sensitivity of P300 amplitude in relation to the

probability of the positive or negative feedback is consistent with earlier P300 studies manipulating probability…that revealed a larger amplitude P3…for subjectively unexpected stimuli compared to expected stimuli" (Fielding et al., 2017, p. x). It is worth remembering that the P300 was discovered in the context of visual and auditory oddball paradigms, where larger P300 was observed for rare (e.g., X) relative to more frequent (e.g., O) stimuli (see Polich, 2007, for a review). For these original experiments comparing the common presentation of O with the occasional presentation of X, there is no sense in which the neural response to O also uniquely represents success and the neural response to X also uniquely represents failure, and the same may well be true of Fielding et al. (2017).

This parsimonious view is entirely consistent with the data we show in Figure 1B given that larger P3 was generated for less frequent losses relative to more frequent wins, and, the data we show in Figure 3B given that larger P3 was generated for wins relative to losses when both outcomes were roughly equi-probable. The disambiguation of outcome valence and outcome frequency is an important future step (Holyroyd & Krigolson, 2007; Müller, Möller, Rodriguez-Fornells & Münte, 2006) and the study of additional components such as the FRN will allow us to test when such environmental properties come on-line and when they interact. As such, the data from Fielding et al.'s (2017) 50/50 condition, where wins and losses were equi-probable, would be particularly instructive. We believe this would help to address an account of stimulus probability, such that if their P3 response was predominately sensitive to presentation frequency, then P3 amplitude should scale with the relative rarity of the event.

Conclusion

The examination of neural responses to successes and failures are critical contributions to understanding how individuals approach, engage and withdraw from variable-outcome environments, incorporating many forms of gambling contexts. Moreover, understanding the contribution of individual reinforcement history in terms of wins and losses will help understand some of the conditions under which gambling cycles are perpetuated. Fielding et al. (2017) provide a potentially useful paradigm for exploring these issues, but we believe the current status of their data are ambiguous with respect to the claim that the brain's reward response occurs even without actual reward.

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Figure Captions

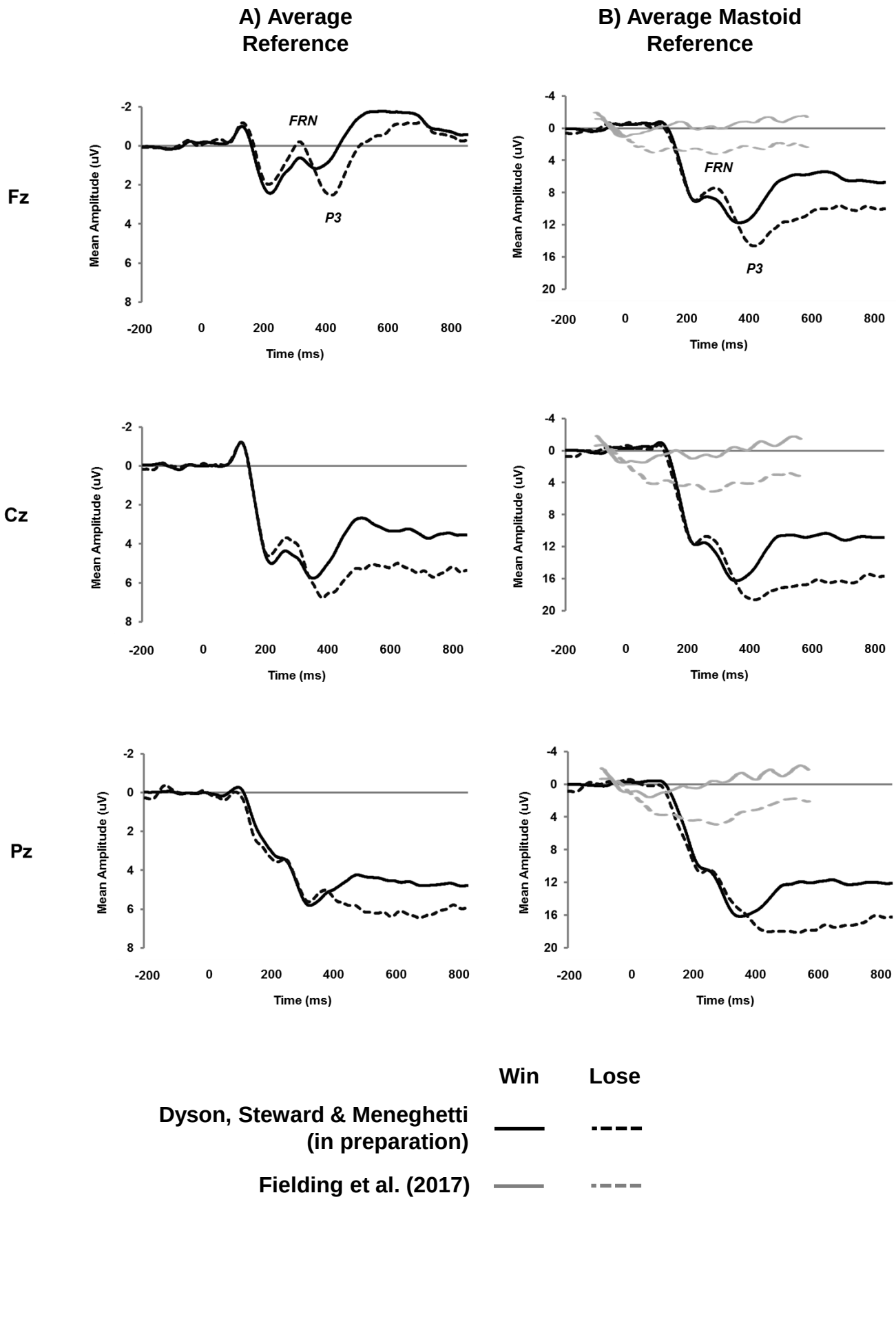
Figure 1. a) Group-average ERP generated by explicit feedback (win, lose) across three mid-line electrodes (Fz, Cz, Pz) following a) average referencing, and b) average mastoid re-referencing. Event-related potential responses of FRN (feedback-related negativity) and P300 are clear in both cases. Black lines represent win (solid) and loss (dotted) data from our lab, grey lines represent replotted data from Fielding et al. (2017).

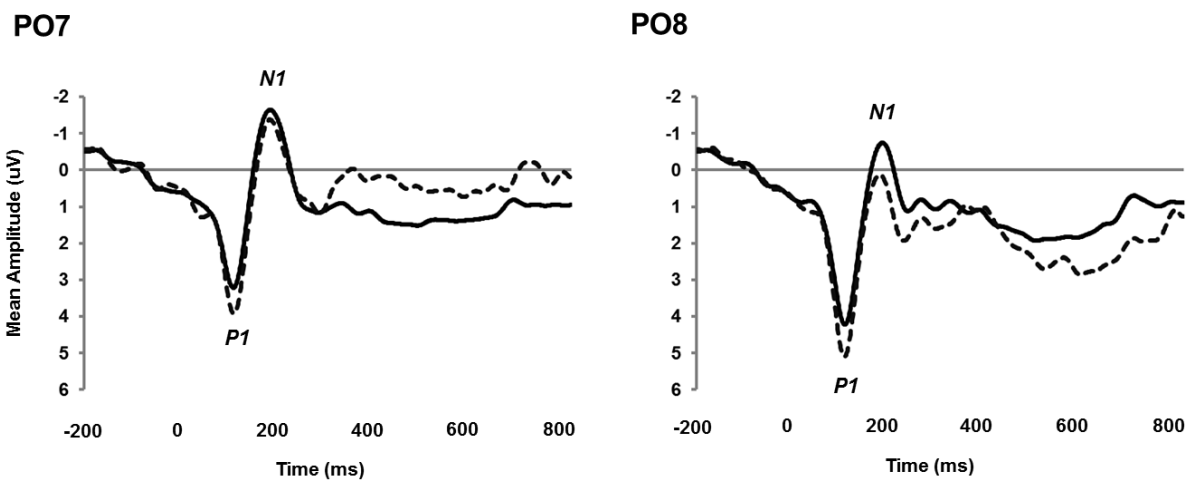
Figure 2. Group-average ERP generated by explicit feedback (win, lose) across two parieto-occipital electrodes (PO7, PO8) following average referencing. Visual evoked responses of P1 and N1 are clear in both cases.

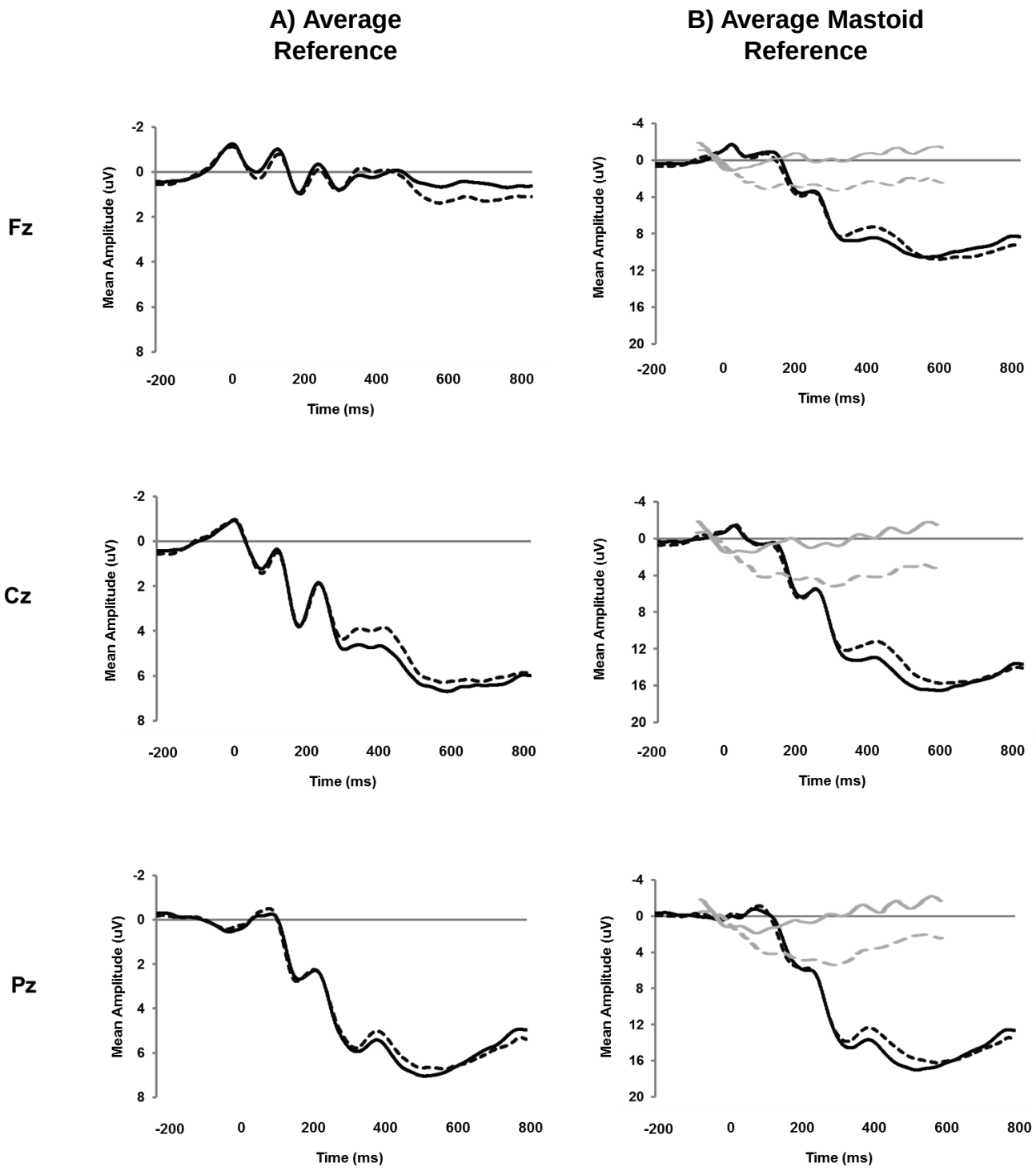
Figure 3. Group-average ERP generated by early, implicit feedback (win, lose) across three mid-line electrodes (Fz, Cz, Pz) following a) average referencing, and b) average mastoid re-referencing, replotted from Forder & Dyson (2016). Black lines represent win (solid) and loss (dotted) data from our lab, grey lines represent replotted data from Fielding et al. (2017).

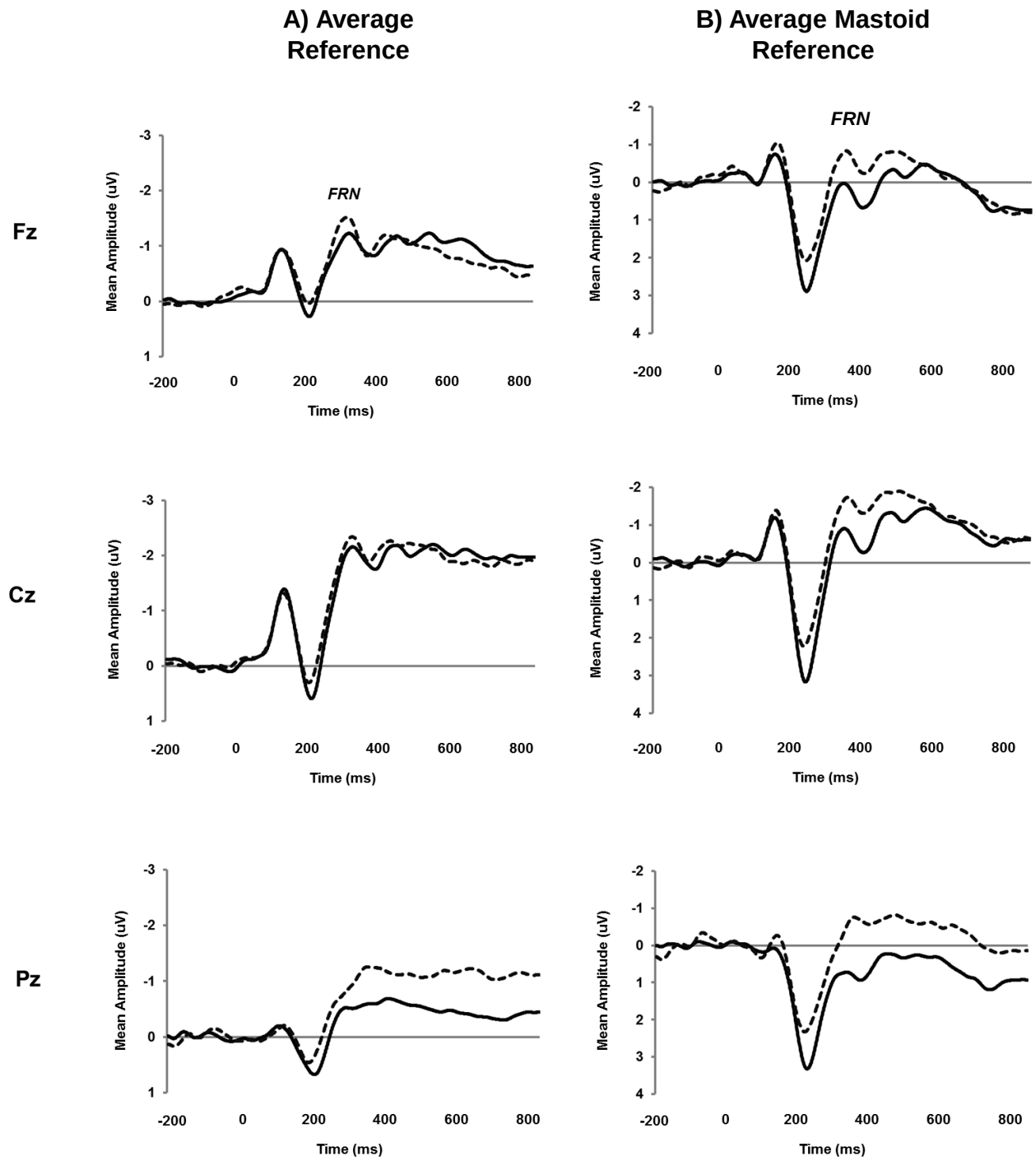
Figure 4. Group-average ERP generated by later, explicit feedback (win, lose) across three mid-line electrodes (Fz, Cz, Pz) following a) average referencing, and b) average mastoid re-referencing, replotted from Forder & Dyson (2016).

Figure


A) Average Reference
B) Average Mastoid Reference
Fz
Cz
Pz
FRN
P3
Mean Amplitude (uV)
Time (ms)
-200
0
200
400
600
800
Win
Lose
Dyson, Steward & Meneghetti (in preparation)
Fielding et al. (2017)


PO7
N1
P1
Mean Amplitude (uV)
-2
-1
0
1
2
3
4
5
6
-200
0
200
400
600
800
Time (ms)
PO8
N1
P1
-2
-1
0
1
2
3
4
5
6
-200
0
200
400
600
800
Time (ms)


A) Average Reference
B) Average Mastoid Reference
Fz
Cz
Pz
Mean Amplitude (uV)
Time (ms)
-200
0
200
400
600
800
Win
Lose
Forder & Dyson (2016)
Fielding et al. (2017)


A) Average Reference
B) Average Mastoid Reference
Fz
Cz
Pz
FRN
FRN
Mean Amplitude (uV)
Time (ms)
-3
-2
-1
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1
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3
4
-200
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200
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600
800
Win
Lose
Forder & Dyson (2016)